International Journal of the Physical Sciences Vol. 5(17), pp. 2590-2597, 18 December, 2010
Available online at http://www.academicjournals.org/IJPS
ISSN 1992 - 1950 ©2010 Academic Journals

Full Length Research Paper

The study of the effect of protective devices performance on voltage sag due to distribution network faults

Mostafa Alinezhad[1], Iman Sepehri rad[2], Seyed Esmaeel Naghibi[3] and Mehrdad Ahmadi Kamarposhti[1*]

[1] Department of Electrical Engineering,Islamic Azad University, Jouybar Branch, Jouybar, Iran.
[2]Golestan Electric Power Distribution. CO, Gorgan, Iran.
[3] Department of Electrical Engineering, Islamic Azad University, Behshahr Branch, Behshahr, Iran.

Accepted 1 December, 2010

Voltage sag is one of the most common power quality disturbances in electric networks. It is necessary to investigate voltage sag due to consumers' vulnerability. Faults are the main cause of voltage sags in distribution networks. Fault in distribution networks according to its specifications (its location, duration and time) can cause an interruption or a voltage sag at the nodes of the network. By making random faults, the voltage sag in such networks can be investigated. In this paper, the effect of protective devices performance such as recloser and fuse in voltage sag due to distribution network faults using MATLAB Software has been evaluated.

Key words: Voltage sag, fault, recloser, fuse.

INTRODUCTION

Today, power quality problem is one of the important issues in power systems. One of the most significant issues regarding power quality is voltage sag. Voltage sags are incidents that reduce the voltage amplitude for a short time. Creating problems for a wide range of equipment is the main cause to study voltage sags. Voltage sags can be harmful for some equipment such as drives or computers and cause significant financial damages. To study voltage sag the following points should be considered.

Firstly, voltage sags are disturbances that arise by faults (short-circuit), energizing power transformers, starting electrical motors and sudden changes of loads. All these cases are classified as disturbances with low or moderate frequency. Secondly, faults are the main cause of voltage sag in distribution networks. Thirdly, variable loads with time are different. Therefore voltage sag effects depend on what occurs and the difference between the loads (Juan and Jacinto, 2006).

Several indices have been proposed to assess the voltage sag performance of a power system ((IEEE P1564, 2004; Brooks et al., 1998; Thallam and Heydt, 2000; Lee et al., 2004). They provide a count of event frequency and duration, the undelivered energy during events, or the cost and severity of the disturbances. Most of these indices are included in the draft of IEEE P1564 (2004). A thorough analysis of power-quality indices, their advantages and limitations are presented in a CIGRE Working Group report (CIGRE Rep, 2004).

This paper discusses the main types of faults that cause voltage sag in distribution networks and results are evaluated by using MATLAB software.

MODELING SYSTEM COMPONENTS

Generally, transient disturbances associated with voltage sag, if only due to faults are classified as transient

*Corresponding author. E-mail: m.ahmadi@jouybariau.ac.ir. Tel: +98-124-3363191. Fax: +98-124-3363190. Post code: 47761-86131.

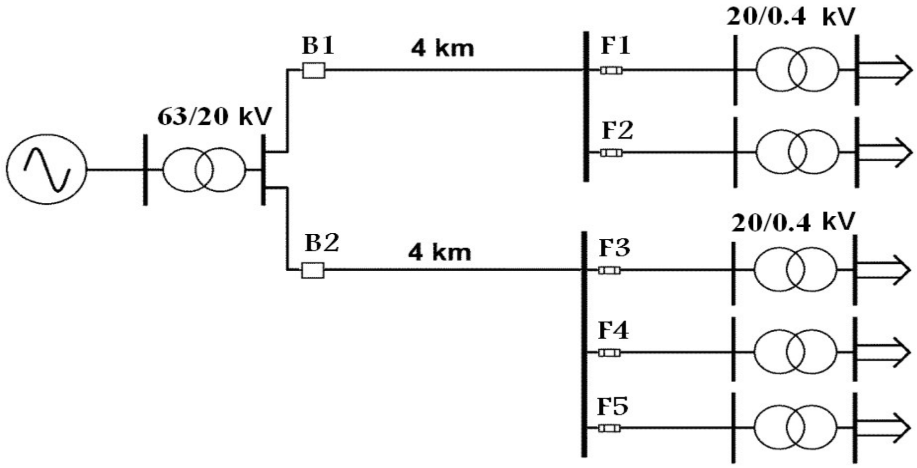


Figure 1. Diagram of the test system.

disturbances with low or moderate frequency (IEEE P1564, 2004); therefore, models for the system components should be able to perform correctly around these frequencies (around 5 kHz). The list of developed models for computing voltage sag can be divided into several groups such as lines and cables, transformers models, load etc. For modeling, lines and cable parameters can make use of compressed equivalent parameters or π circuits, constant distributed parameter model in a certain frequency and/or distributed model depending on the frequency.

Obviously, extended model dependent on frequency is the best choice to simulate, but it is time consuming. Therefore compressed parameter model that also give acceptable results is used. Transformer can be used for modeling, both linear and nonlinear models. If voltage sag is caused by transformer energizing, saturation of transformer will be very important, so it is necessary to use nonlinear models (Math and Bollen, 2000). But in this paper we will study voltage sag due to distribution network faults and in most cases, transformers are not saturated during the disturbance. Linear and nonlinear models give almost similar results, so the linear model is used. Of course this does not mean that the simulation results obtained from linear and nonlinear transformers are the same. Because when the voltage is retrieved, the process creates an inrush current that only a nonlinear model can be shown correctly. In order to model load, constant impedance model (that is a parallel or series RL load) has been used.

THE STUDY OF VOLTAGE SAG DUE TO DIFFERENT TYPES OF FAULTS

Figure 1 shows the diagram of a test system used in this paper. The low voltage side of the substation transformer is Y-connected and is grounded by means of a reactor of 0.01 Ω per phase. This grounding system limits over currents caused by single-phase-to-ground faults. The high voltage side of the substation transformer is Δ-connected. At MV and LV sides of transformer, single-phase-to-ground fault (LG), two-phase-to-ground fault (2LG), two-phase fault (2L) and three-phase fault (3L) will be examined and the results can be evaluated.

The probabilities of each type of faults are as follows:

LG = 75%, 2LG = 17%, 3LG = 3%, 2L = 3%, 3L = 2%

Thus, single-phase-to-ground fault and two-phase-to-ground fault will be considered further. The results (voltage-time curve) are shown in Figures 2 to 5. The results of operations performed by the procedure implemented in MATLAB can be summarized as follows.

(1)The retained voltage during a three-phase fault at the secondary of the substation can be approximated by means of the following expression:

$$V_{sag} \approx \frac{R_f}{Z_s + Z_{TR} + R_f} . V_{(pre-sag)} \tag{1}$$

Where Z_S and Z_{TR} are, respectively the impedances of the high-voltage (HV) equivalent and the substation transformer; R_f is the fault resistance, while $V_{(pre\text{-}sag)}$ and $V_{(sag)}$ are the voltages prior and during the fault, respectively. This formula shows that if the impedance of substation transformer is large enough, with a low fault resistance, not many equipment trips should be caused by three-phase faults (Math and Bollen, 1996; Caldron et al., 2000).

(2) If customer equipment is installed only at the low voltage side, as assumed in this work, the percentage of

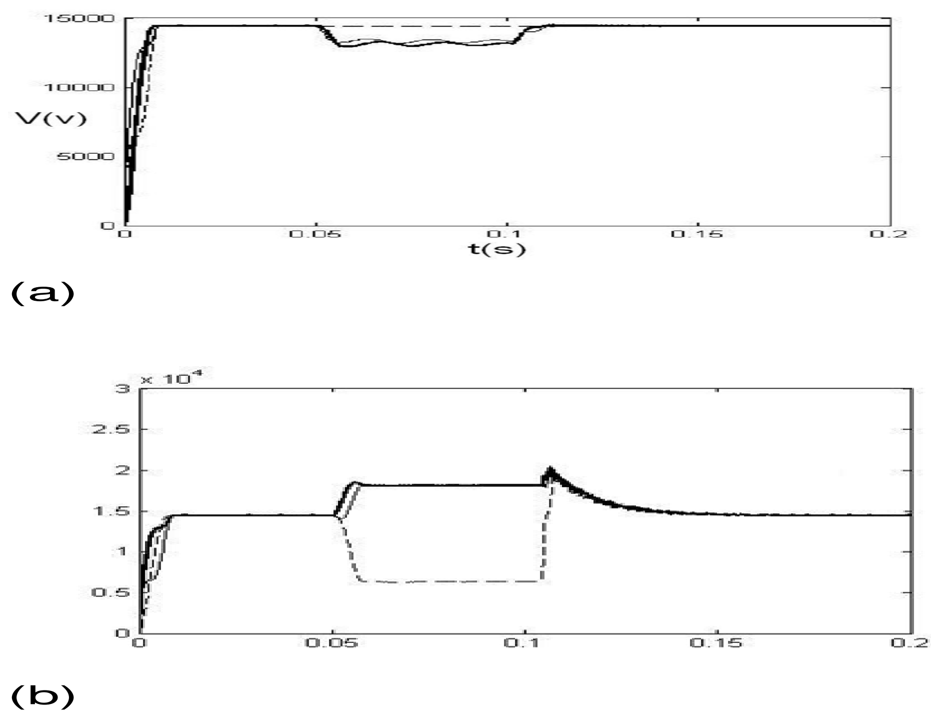


Figure 2. Voltage sags caused by a single-phase-to-ground fault. (a) Voltage sag—LV side. (b) Voltage sag—MV side.

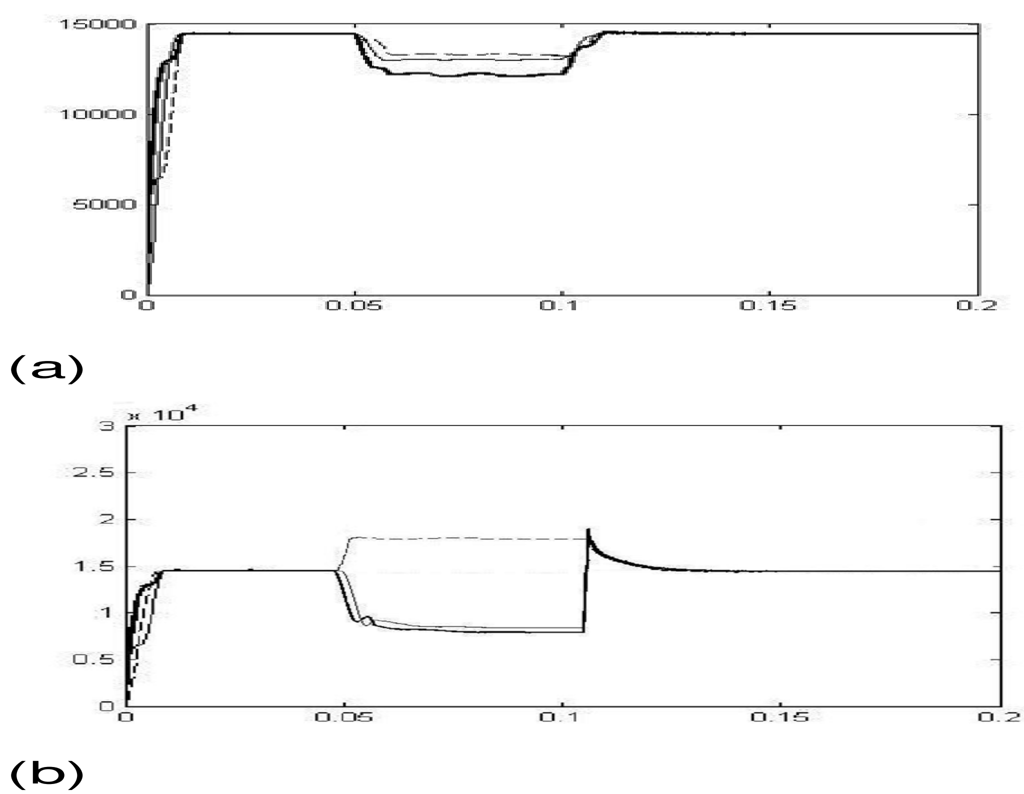
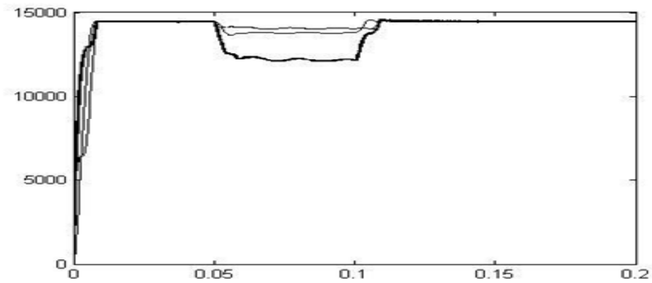
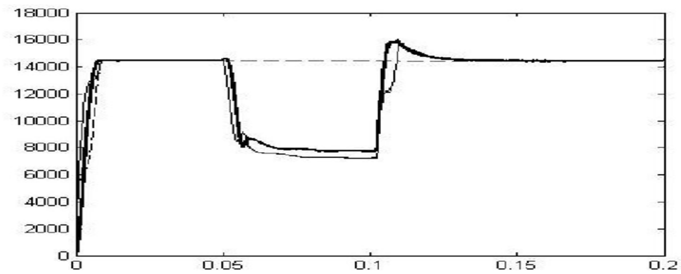


Figure 3. Voltage sags caused by two-phase-to-ground fault. (a) Voltage sag—LV side. (b) Voltage sag—MV side.

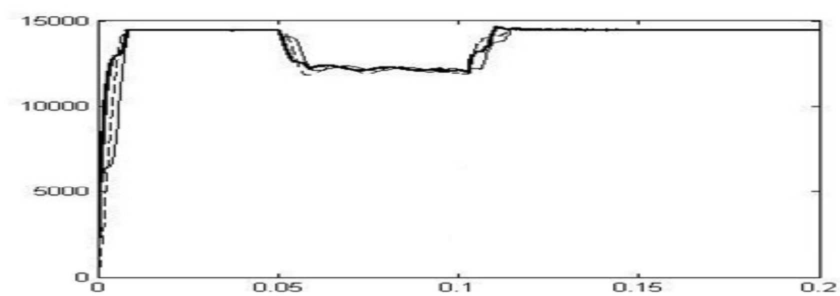


(a)

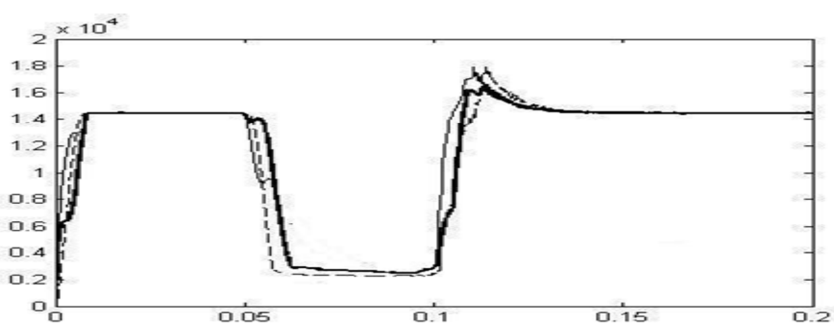


(b)

Figure 4. Voltage sags caused by a two-phase fault. (a) Voltage sag—LV side. (b) Voltage sag—MV side.



(a)



(b)

Figure 5. Voltage sags caused by three-phase fault. (a) Voltage sag—LV side. (b) Voltage sag—MV side.

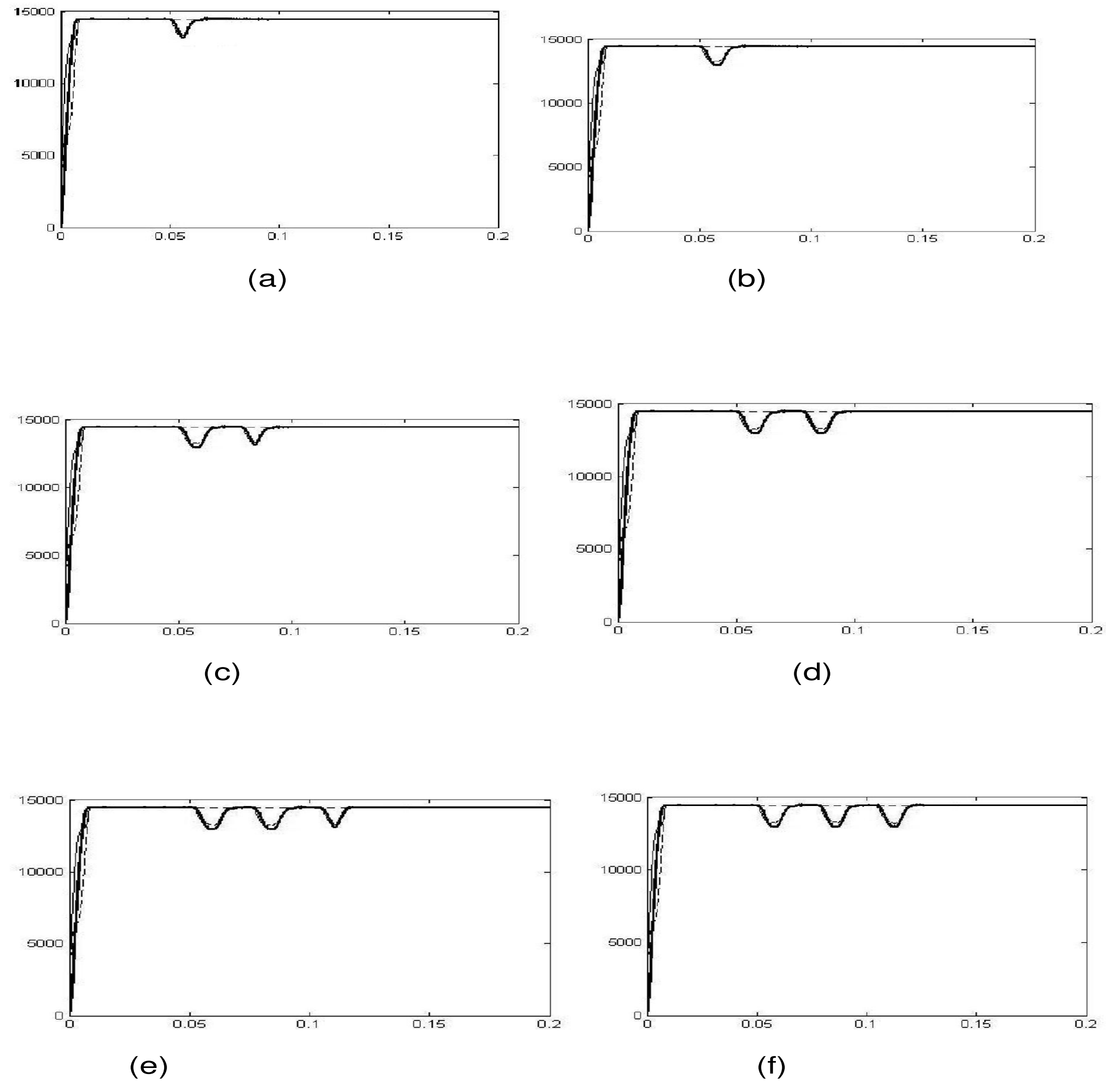


Figure 6. Voltage sag caused by a single-phase-to-ground fault at LV side for healthy phases — Two reclosing intervals (a)$t_F<t_C$, (b)$t_F<t_C+t_R$,(c) $t_F<2t_C+t_R$, (d) $t_F<2t_C+2t_R$,(e) $t_F<3t_C+2t_R$ and (f) $t_F>3t_C+2t_R$.

trips due to single-phase-to-ground faults will significantly decrease.

(3) Depending on the distribution voltage level and the transformer grounding system, only those faults originating not far from the substation terminals will cause severe voltage sags.

(4) Type of transformer influence on type of voltage sag at MV side of transformer is significant and can increase or decrease the voltage of different phases during the fault.

ANALYSIS OF VOLTAGE SAG WITH PROTECTIVE DEVICES

In this section we study voltage sag due to faults in the system with protective devices such as fuse and recloser and effects of protective devices. In the first step we study the system only with recloser and in the second step considers the system with recloser and fuse.

The operation of recloser as a protective device influences voltage sag. For instance, unsuccessful reclosing after a fault can cause two or more voltage sags.

The reclose operations have different effects on faulted and healthy feeders. An important aspect is then the characterization of these effects. In this paper, recloser with two reclosing intervals is considered and the effect of reclosing intervals on faulted and healthy feeders will be studied.

Figures 6 and 7 show different clusters of voltage sags at faulted and healthy feeders caused by single-phase-to-ground (the most important type of fault).

Assume that t_F, t_C, t_R and t_S are respectively the fault

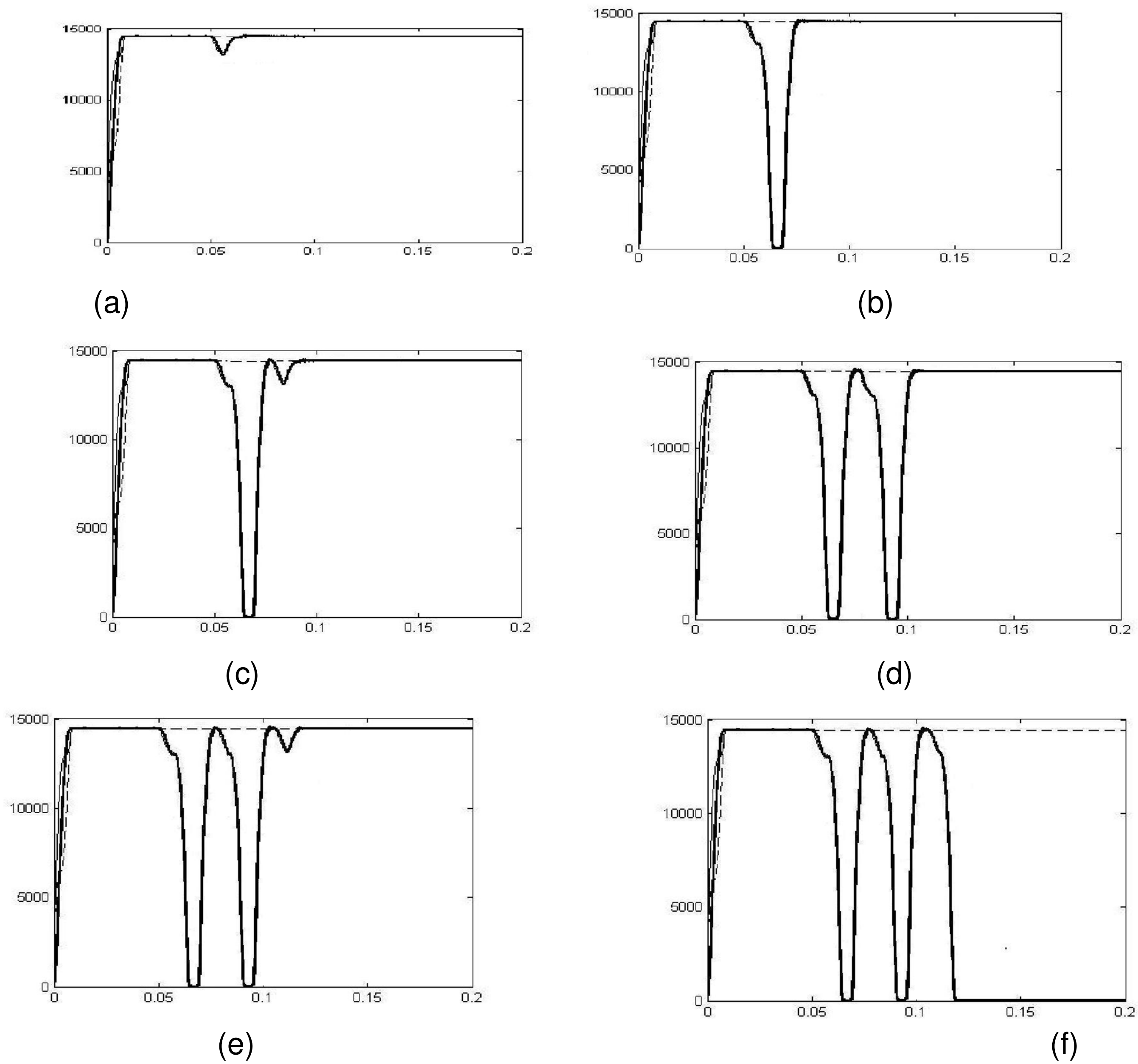


Figure 7. Voltage sag caused by a single-phase-to-ground fault at LV side for faulted phases— Two reclosing intervals. (a)$t_F<t_C$, (b)$t_F<t_C+t_R$, (c) $t_F<2t_C+t_R$, (d) $t_F<2t_C+2t_R$, (e) $t_F<3t_C+2t_R$ and (f) $t_F>3t_C+2t_R$.

duration, the fault-clearing time, the reclosing interval and the sag duration. If the fault duration is shorter than the fault-clearing time ($t_F<t_C$), the recloser cannot detect the fault and the fault cannot cause a recloser operation. So the sag duration that is seen by consumers at faulted and healthy feeders is equal ($t_F=t_C$).

If the fault duration is increased, the consequences can be different; the fault can cause a recloser operation. If the fault causes an interruption before than recloser operation, the sag duration will be the total time of tC and t_R at faulted feeder and consumers will experience short interruption.($t_S=t_C+ t_R$) and the sag duration and the fault-clearing time is equal at healthy feeder($t_S=t_C$).

If the fault disappears after the first reclosing interval and before the second reclosing interval t_S is equal to t_F at faulted feeder ($t_S=t_F$). And this time is shorter than $2t_C$ at healthy feeder ($t_S<2t_C$).

If the fault disappears during the second reclosing interval, then $t_S=2t_C+2\ t_R$ at faulted feeders and $t_S=2t_C$ at healthy feeders.

If the fault disappears after second reclosing interval and before the third time of fault detection, then $t_S<3t_C+2t_S$ at faulted feeders and $t_S<3t_C$ at healthy feeders.

In all these cases, healthy feeders will experience instantaneous voltage sag and faulted feeders will experience a short interruption. But if the fault does not disappear after second reclosing interval and before the third time of fault detection, faulted feeders will experience a long interruption and healthy feeders will experience instantaneous voltage sag ($t_S=3t_C$) .

The main results obtained are summarized below:

(a) For nodes located on the faulted feeder, the fault will always cause an interruption, whose duration will depend on the fault current and the reclosing interval; if the fault duration is long enough, the interruption could be sustained.
(b) The number of interruptions at each node will decrease if the fault-clearing time of the recloser is increased.
(c) With a constant number of load nodes, the number of nodes that will experience an interruption every time a fault is produced will decrease if the number of feeders in the network is increased.
(d) The sag duration seen by nodes located on the healthy feeders does not depend on the reclosing interval t_R.

The results of simulation of voltage sag with two reclosing intervals are in appendix (Table 1). Using fuses as protective devices in the power system influences voltage sag and interruption and will change duration and number of trips due to faults considering time –current curve of fuses.

The consequences of fuse operation can be also predicted:

(1) If the fault duration is short enough and no fuse operation is caused, the sag duration will be that of the fault, and the retained sag voltage will be the during-fault voltage ,at all system nodes.
(2) If the fault causes a fuse operation, the faulted phases will remain open for nodes located on the faulted feeder; for nodes located on healthy feeders, the sag duration will be the fault-clearing time and the voltage will be the during- fault voltage. The consequences of these cases can be different. Generally, first and second reclosing interval is faster than fuses operation but if the fault disappears after second reclosing interval, fuse will open faulted phase before the recloser operates and opens the main feeder. This operation is obtained by comparing the time–current curve of fuses and reclosers. Of course at substation feeder, depending on its importance, the fuse can be adjusted to operate faster than the first and second reclosing interval for severe fault and the main feeder has no voltage sag. The coordination between fuses and relays causes the number of voltage sags and trips due to faults to decrease in the system, significantly.

CONCLUSIONS

The results of simulation of voltage sag at faulted and healthy feeders with protective devices show:

1. Type of transformer influence on type of voltage sag at MV side of transformer is significant and can increase or decrease the voltage of different phases during the fault.
2. The sag duration seen by nodes located on the healthy feeders does not depend on the reclosing interval t_R.
3. The coordination between protective devices causes the number of voltage sags and trips due to faults to decrease in the system, significantly.
4. Although, protective devices may in some types of faults increase incidents and intensify low voltage sags, but generally these protective devices decrease voltage sags and trips in the systems and improve systems performance.

REFERENCES

Brooks DL, Dugan RC, Waclawiak M, Sundaram A (1998). Indices for assessing utility distribution system RMS variation performance. IEEE Trans. Power Del., 13(1): 254-259.

Caldron D, Fauri M, Fellin L (2000). Voltage sag effects on continuous industrial proccesses:desentizing study for textile manufacture. in proc.2nd int.conf.power quality, palo Alto ,CA, Electric power research Institute., D-13: 1-7.

CIGRE Rep (2004). Power quality indices and Objectives. Joint Working Group CIGRE c4.7/CIRED.

IEEE P1564 (2004). Recommended practice for the Establishment of Voltage sag Indices. Draft 6.

Juan AM, Jacinto MA (2006). Voltage Sag Studies in Distribution Network—PartI: System Modeling. IEEE Transactions on Power Delivery, 21(3): 1670 -1678.

Lee GJ, Albu MM, Heydt GT (2004). A power quality index based on equipment sensitivity, cost, and network vulnerability. IEEE Trans. Power Del., 19(3):1504–1510.

Math H, Bollen J (2000). Understanding Power Quality Problems. By the Institute of Electrical and Electronic Engineers, Inc.

Math H, Bollen Y (1996). Fast assesment methods for voltage sags in distribution systems. IEEE Trans. On Indystry application, 32(6): 1414 -1423.

Thallam RS, Heydt GT (2000). Power acceptability and voltage sag indices in the three phase sense. in Proc. IEEE Power Eng. Soc. Summer Meeting, Seattle, WA.

APPENDIX

Table 1. Voltage sag characteristics (recloser operation-two reclosing intervals).

Case			Feeders	Duration	Voltage
	$t_F < t_C$		All feeders	$t_S = t_F$	Retained Voltage
$t_F > t_C$	$t_F < t_C + t_R$		Faulted feeders	$t_S = t_C + t_R$	Short interruption
			Other feeders	$t_S = t_C$	Retained Voltage
	$t_F > t_C + t_R$	$t_F < 2t_C + t_R$	Faulted feeders	$t_S < 2t_C + t_R$	Short interruption
			Other feeders	$t_S < 2t_C$	Retained Voltage
		$t_F < 2t_C + 2t_R$	Faulted feeders	$t_S = 2t_C + 2t_R$	Short interruption
			Other feeders	$t_S = 2t_C$	Retained Voltage
		$t_F < 3t_C + 2t_R$	Faulted feeders	$t_S < 3t_C + 2t_R$	Short interruption
			Other feeders	$t_S < 3t_C$	Retained Voltage
		$t_F > 3t_C + 2t_R$	Faulted feeders	$t_S = ?$	Short interruption
			Other feeders	$t_S = 3t_C$	Retained Voltage